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*Study of an Atlas-Agena
Minimum Soft-Landing
Lunar Spacecraft*

H. Bank
E. Lally

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

August 30, 1963

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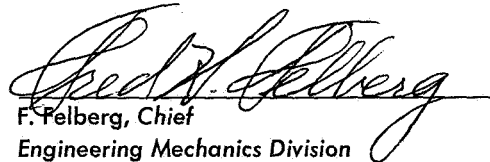
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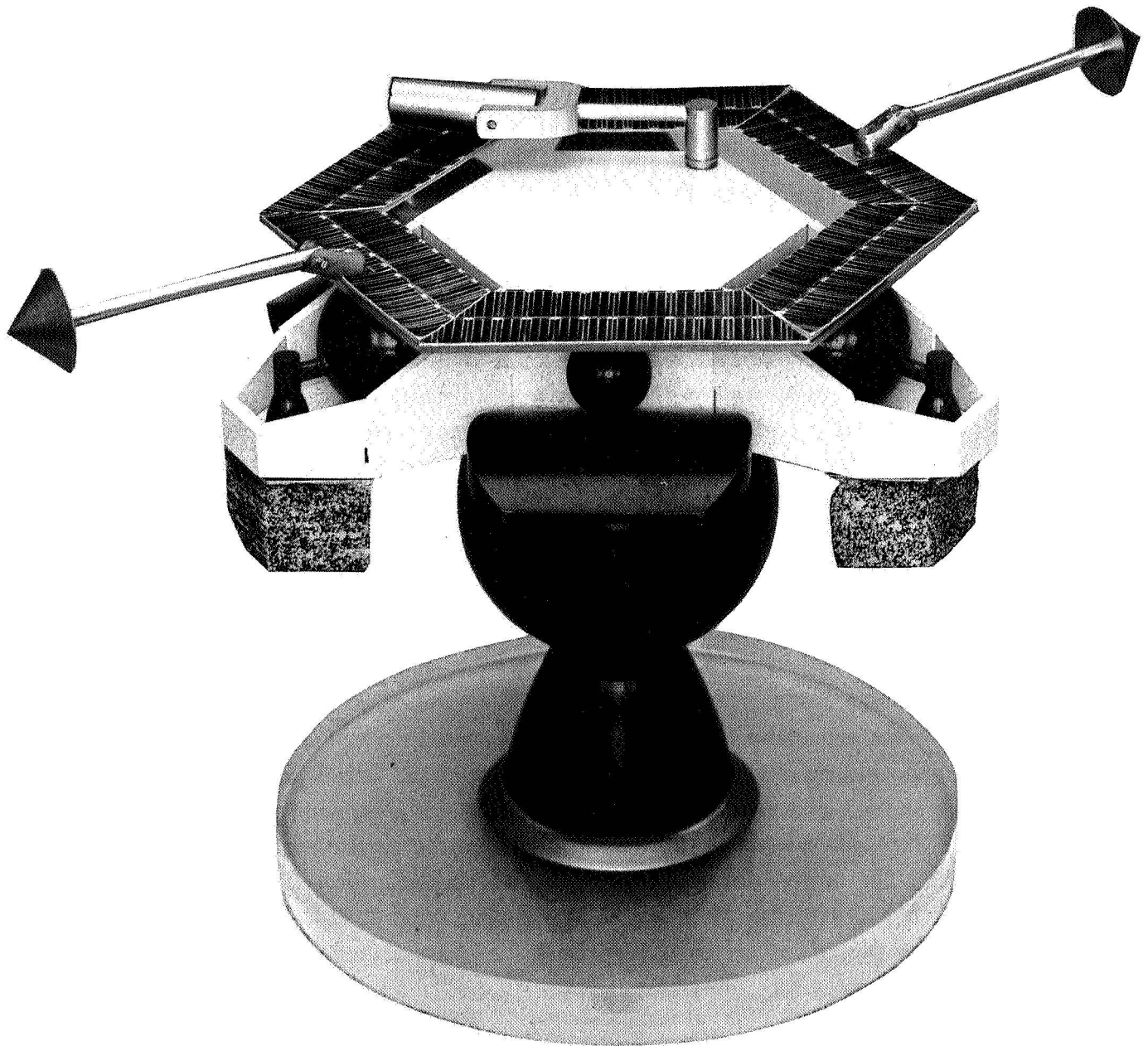
The authors would like to acknowledge the assistance of the *Surveyor* engineering staff of Hughes Aircraft Company, Culver City, California, in performing this study.

ABSTRACT

A study has been made of a spacecraft which can be launched by an *Atlas-Agena* and which has a minimum soft-landing lunar (MSL) capability. This spacecraft was of interest since it could provide a possible supplement to as well as an alternate for the *Surveyor* lunar project, using a developed and proved boost vehicle system. The purpose of this study was to determine the design feasibility of such a spacecraft and to establish the critical development problem areas.

The design presented is within the geometric and performance constraints of the *Atlas-Agena D* booster and meets the minimum mission requirements established for the study; i.e., demonstration of soft-landing technology as well as TV picture and soil-hardness measurements. The injected weight of the spacecraft is approximately 974 lb, which includes a 10% performance contingency. This presents a sensitive performance condition for the 900- to 1,000-lb injection capability of this booster. The incorporation of proposed performance improvements in the booster which increase this capability to 1,100 lb could, however, eliminate this problem and also, perhaps, make additional experiments possible.

The magnitude of the spacecraft development effort is substantial. However, since the MSL is essentially a scaled-down *Surveyor*, few new development problems should be encountered. This is particularly true in the electronics and engineering mechanics area, where many of the *Surveyor* subsystems and components can be used directly in the MSL. The largest development effort will be in the propulsion area, which will probably be the schedule pacing item. It is believed the vernier propulsion system will present the most critical development problem.



I. INTRODUCTION AND SUMMARY

During the early period of the *Surveyor* program, there was considerable interest at the Jet Propulsion Laboratory in the concept of a Minimum-sized Soft-Landing spacecraft (MSL).¹ The purpose of this mission was to demonstrate soft-landing technology and to obtain some minimal scientific information on the lunar-surface environment. In essence, this was a minimum *Surveyor*-spacecraft approach. Limited studies were made of this concept which indicated that the total injected weight required was in the 900- to 1,000-lb class. Since this was beyond the 700- to 800-lb lunar capability of the *Atlas-Agena* at that time, no further studies were considered.

Since then, however, interest has increased in the MSL approach as a result of:

1. Increased payload capability of the *Atlas-Agena*. (A performance-improvement program has increased the payload capability to the 900- to 1,000-lb class. Proposed additional improvements could increase this to a 1,100-lb capability.)
2. Uncertainties in the *Surveyor* schedule and its payload capability. (Both increase the importance of alternatives.)²
3. The possible value of a supplemental *Surveyor* spacecraft for specific reduced missions; i.e., local TV photos, homing devices for large spacecraft, etc.

As a result, it was considered appropriate to investigate an *Atlas-Agena* MSL in greater depth. The purpose of this extended study was to review the concept in sufficient detail to establish the design feasibility and to determine the critical development-problem areas.

¹Reference Memoranda dated Nov. 3, 1961 and Oct. 23, 1962.

²There are at least two possible alternatives for the *Surveyor* mission based on the current lunar-program schedule. One is the minimum soft-landing approach which uses a developed booster but which requires a new spacecraft. The other considers the use of a new booster made up of developed stages (*C-1* plus *Agena* or *Titan II* plus *Agena*) using the current *Surveyor* spacecraft. Both of these alternatives have their merits and should be investigated.

Recognizing the influence of the Lunar Program schedule on the merits of this spacecraft, it was considered appropriate to minimize the critical-problem areas by taking advantage of the *Surveyor* developments. Specific guidelines of the study were:

1. Use of the *Atlas-Agena* booster constraints specified for *Mariner C*.
2. Incorporation of the *Surveyor* system, using *Surveyor* components and flight operations to the maximum extent possible
3. Use of the *Surveyor* "state-of-the-art" where changes in spacecraft size or mission require modification of *Surveyor* subsystems or components

Results of the design investigation are shown on the configuration drawing of Figs. 1 through 4. Although this may not be the optimum spacecraft design for the mission, it is believed to be a feasible approach that meets the constraints of the study.

The estimated landed weight of this spacecraft is 259.4 lb, approximately 15% of which is associated with experiments. The total injected weight for this spacecraft is 885 lb. However, allowing a 10% contingency³ in the hardware weights, the injected payload required for this spacecraft design is 974 lb. This weight presents a sensitive performance situation for the current *Atlas-Agena* payload capability of 900 to 1,000 lb. However, proposed improvements in the booster system indicate that a payload capability of approximately 1,100 lb could be obtained. If such improvements were implemented, they would remove the performance sensitivity of this approach and perhaps make additional experiments possible.

³The 10% contingency allows for two compensating factors: (1) the limited study depth and (2) the fact that a large number of component weights come directly from existing hardware.

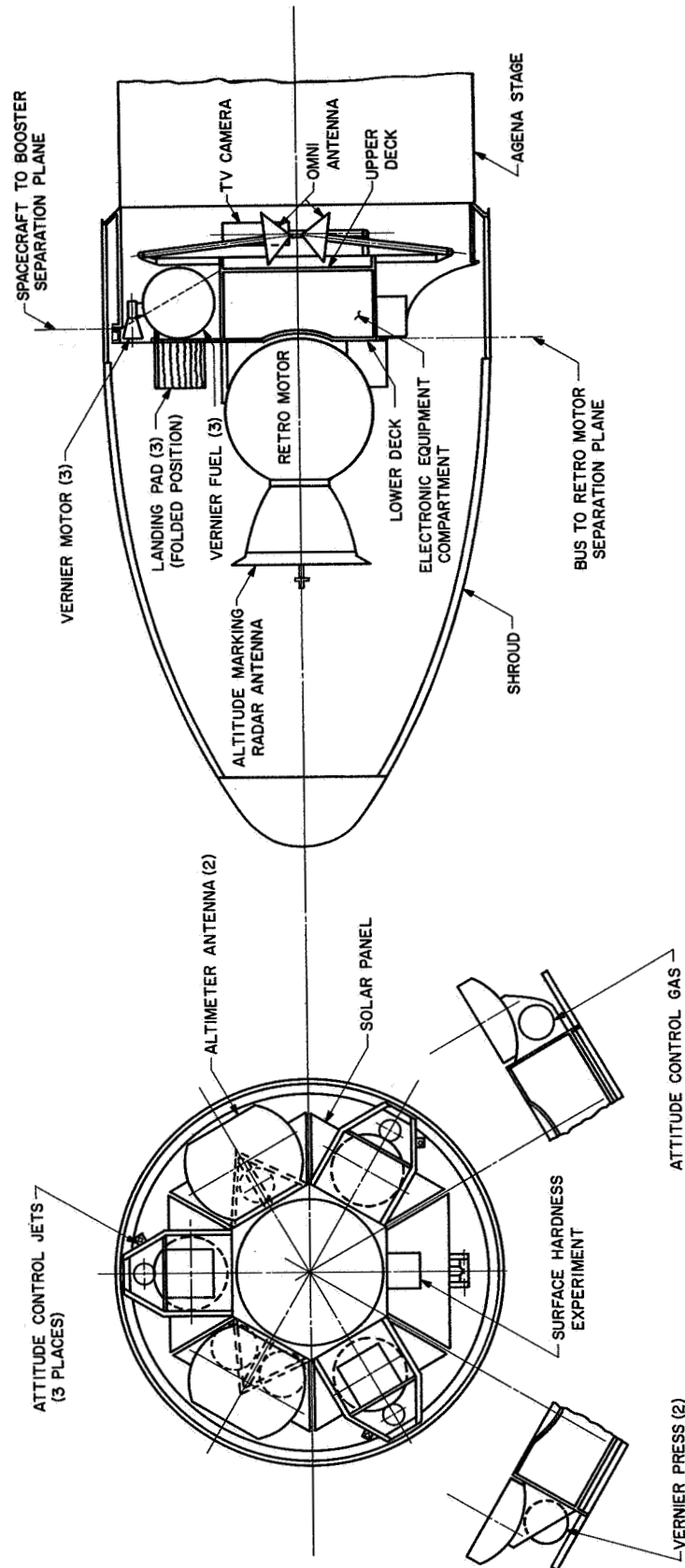


Fig. 1. Lunar soft-lander configuration

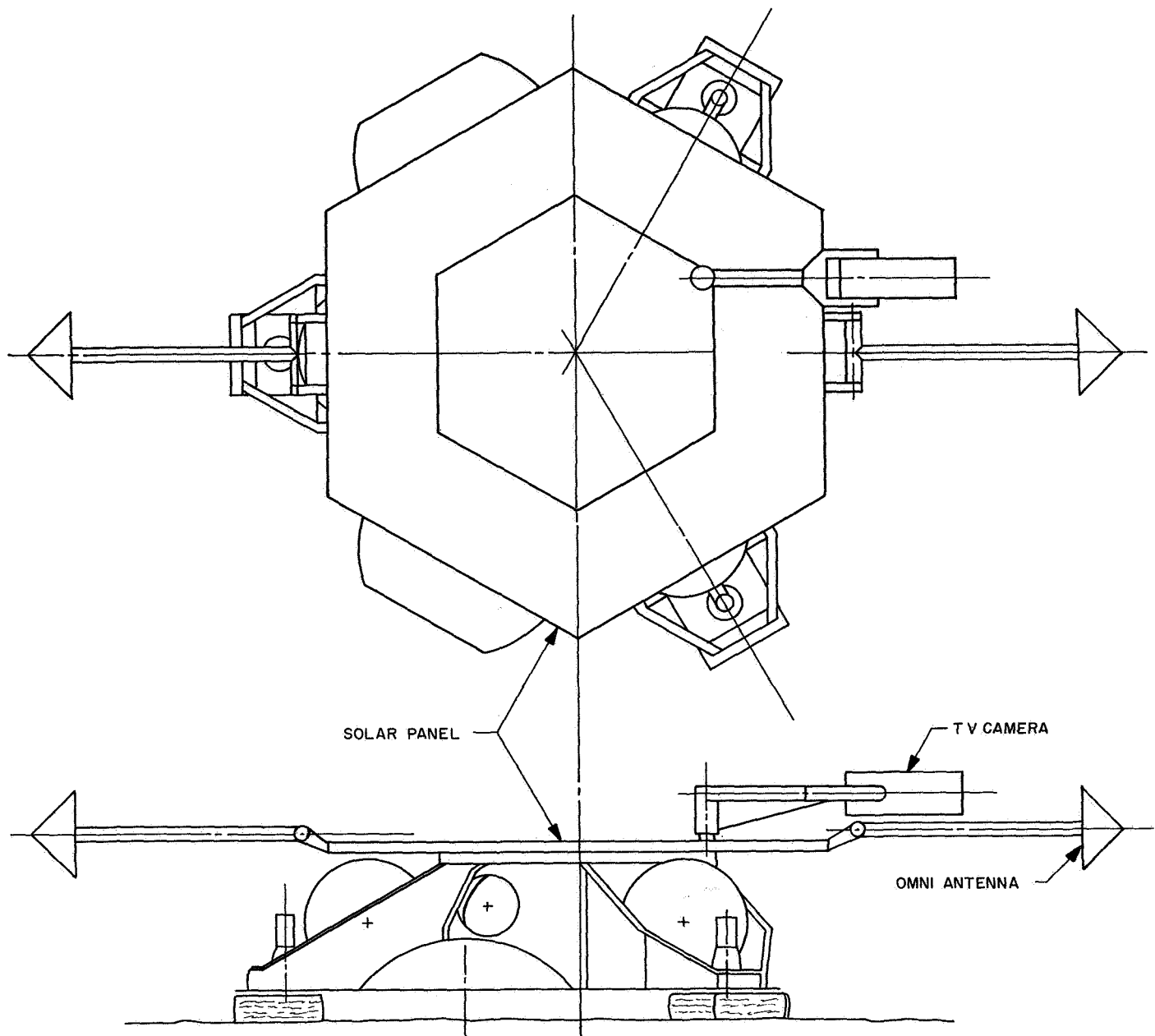


Fig. 2. Landed configuration

By using the *Surveyor* scheme of spacecraft operations, the magnitude of the engineering developments in the electronic, mechanical, and propulsion systems has been minimized. This is particularly true in the flight sensor and electronics area because many of the *Surveyor* subsystems and their components could be used directly (or perhaps with minor modification) in the MSL. Problems in the engineering-mechanics area are also nominal; however, the propulsion area probably involves appreciable development effort. Considering these propulsion problems, the reduced total impulse

required by the smaller spacecraft (approximately 45% of *Surveyor*) changes the main solid retro motor from a 37- to a 25-in. diameter. This change involves appreciable development effort. However, it does not present any new development problems, particularly since this size of spherical motor (25-in. D) had already been partially developed (3 test firings) for a space-propulsion project approximately 2 yr ago.

More difficult propulsion problems are concerned with the scaling down of the *Surveyor* vernier propulsion sys-

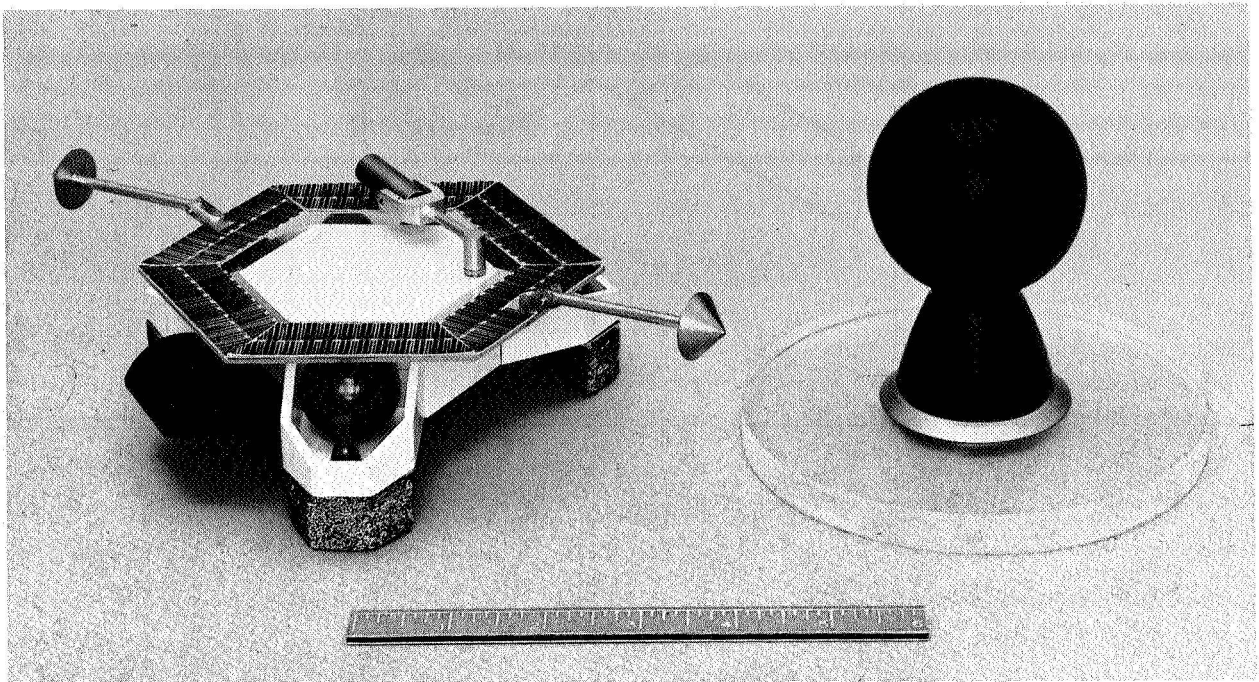


Fig. 3. Model of minimum soft-lander

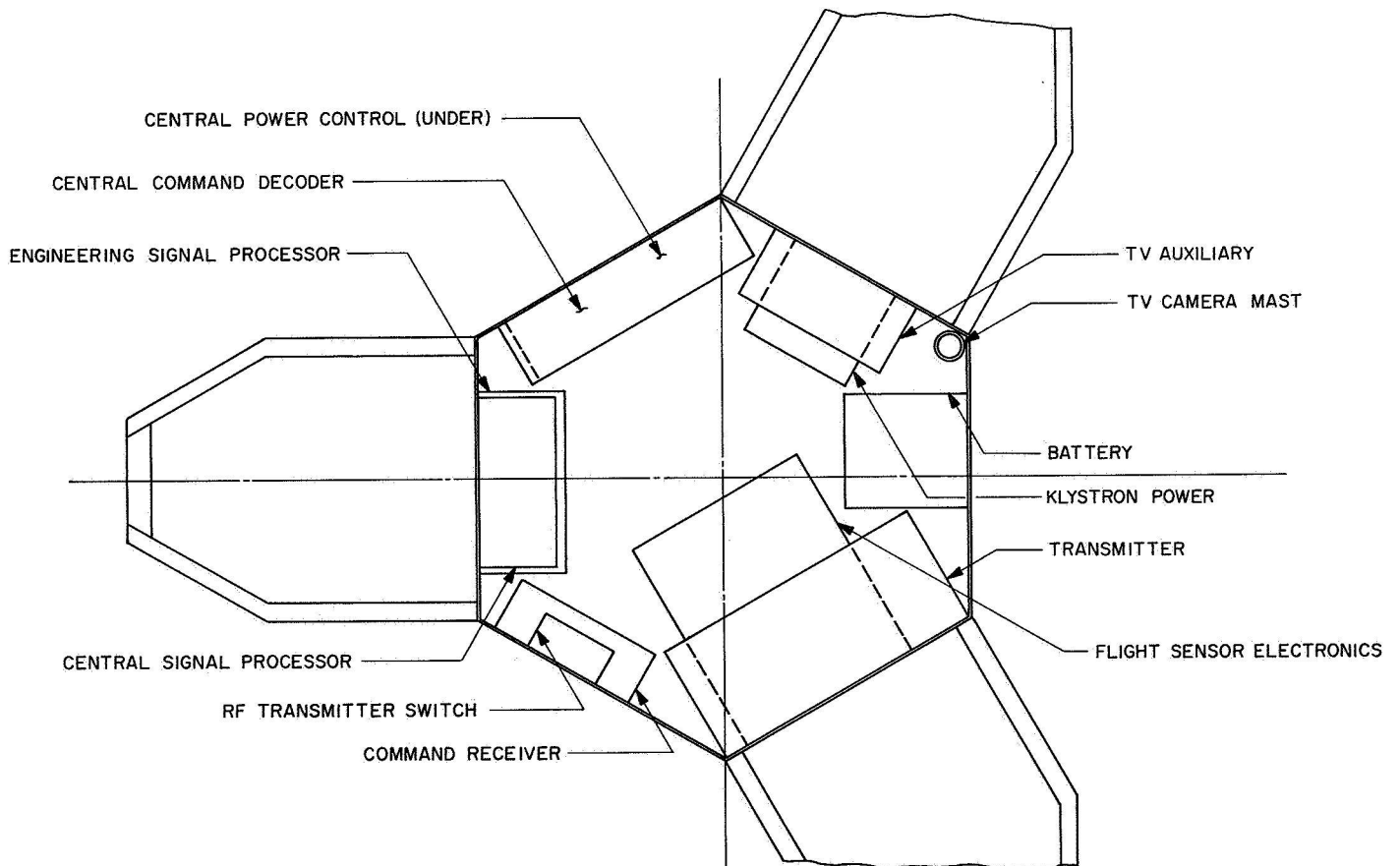


Fig. 4. Electronic equipment compartment

tem, which is an advanced state-of-the-art system. The critical component of this system is the regeneratively cooled vernier motor. It is currently having troubles in the *Surveyor* program because of the limited cooling capacity of the fuel (monomethyl-hydrazine) in the low-thrust condition and heat soak-back causing decomposition after engine shutdown. Scaling down in size to less than one-half of the minimum *Surveyor* thrust level therefore aggravates an already sensitive problem. However, because of these same difficulties, the *Surveyor*

program is currently considering the use of an ablative-cooled vernier system developed by industry. This new system has been tested repeatedly and found to be relatively insensitive to the thrust levels and throttle ratios applicable to *Surveyor* or to this minimum soft-lander. Should this ablative-cooled system be qualified for the *Surveyor* flight program, it should be considered for the MSL. In any event, this system will probably be one of the most critical development problems of the MSL spacecraft.

II. MISSION CONSIDERATIONS

Since the MSL was considered an alternate as well as a possible supplement to *Surveyor*, the objectives of the two spacecraft missions are identical:

1. To demonstrate lunar soft-landing technology
2. To obtain lunar environment characteristics (particularly TV and surface-hardness information) for the manned lunar program
3. To obtain lunar scientific information

Objective 1, which is of primary importance, is accomplished by normal MSL performance. However, because of the reduced payload capability of the MSL, it was necessary to approach *Surveyor* objectives 2 and 3 on a multiple mission basis. A detail review was then made of the *Surveyor* experiments and their subsystem requirements (Table 1). The purpose of this review was to find a common denominator that would fit the experiments efficiently into a minimum number of successive flight-test payloads for the MSL.

This review resulted in the adoption of (1) a 35-lb weight limitation for the payload, (2) a communications system capable of transmitting TV, and (3) a nominal 1/2- to 1-hr lifetime for experiments. This payload definition was chosen since it accomplished objectives 1 and 2 on one flight. It also provided the capability of a ma-

jority of the current as well as future *Surveyor* experiments. The only experiments beyond this capability involve the soil chemical composition and physical characteristics equipment using the X-ray diffraction or drill approach (60-lb weight). It was considered appropriate to omit this experiment from the current MSL payload since somewhat similar information was obtained from the alpha-scattering tests. These heavier experiments were considered appropriate for possible future MSL missions at a time when increased booster performance might be available.

Table 1. *Surveyor* lunar experiments

Current experiments		Proposed experiments	
Experiment	Weight ^a , lb	Experiment	Weight ^a , lb
TV	25	Surface temperature	5
Soil mechanics	10	Thermal diffusivity	10
X-ray diffraction	60	Magnetic susceptibility	5
Alpha scattering	10	Acoustic velocity	5
Meteorite experiment	5	Density	5
^a Weight estimates consider modified versions of current <i>Surveyor</i> experiments; the weights include experiment power.			

III. BOOSTER CONSIDERATIONS

The *Atlas-Agena* booster constraints (particularly payload capability) are quite sensitive to the flight schedule because of the continual improvements being introduced into the booster system (see Fig. 5). Therefore, in order to establish the appropriate booster constraints, it was necessary to estimate a development schedule for this mission. A preliminary estimate of 1½ to 2 yr was believed appropriate, based upon past experience in the development of main and vernier retro propulsion systems for spacecraft. These are believed to be the pacing items.

Using the late 1964 to 1965 period as the estimated flight dates, the booster considered appropriate for this study was the improved *Atlas-Agena B* vehicle. This booster is currently being used for the *Mariner C* planetary mission. The constraints of this booster are listed below.

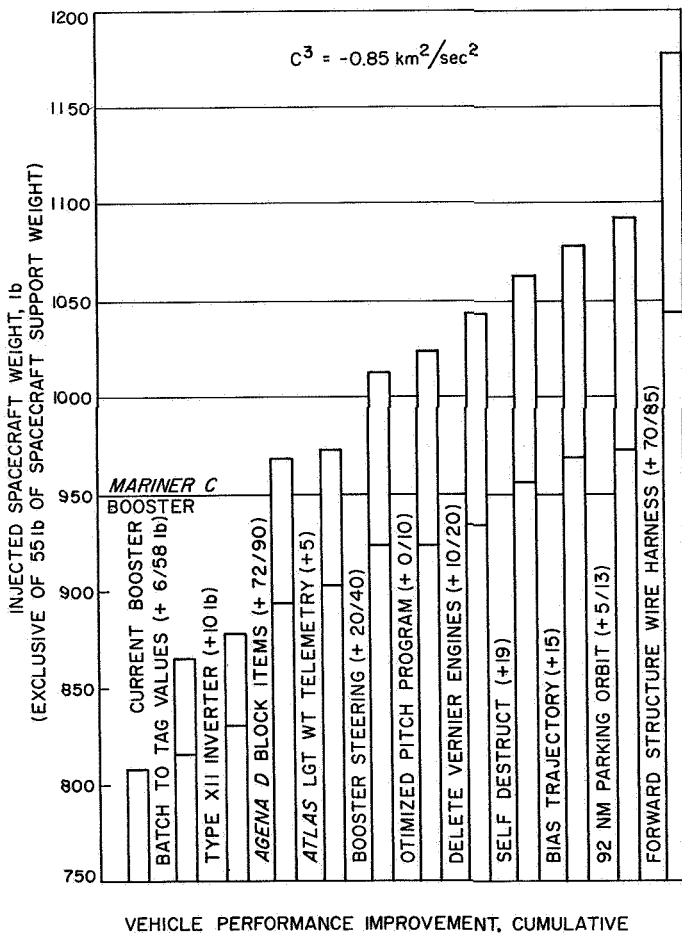


Fig. 5. Injected lunar payload capability of *Atlas D-Agena D*

1. Payload Considerations

The nominal planetary payload capability of this booster for the 1964 to 1965 period (*Mariner C*) has been estimated at 640 lb. (Spacecraft weight = 570 lb, spacecraft support weight = 70 lb.) Since this performance is at a C_3 energy level of $10.2 \text{ km}^2/\text{sec}^2$ and the *Surveyor* mission at $-0.85 \text{ km}^2/\text{sec}^2$, the equivalent lunar payload capability is⁴

$$W_{PL} = 640 + 33 [10.2 - (-0.85)] = 1,005 \text{ lb}$$

Allowing 55 lb for the spacecraft support weight, the injected weight is

$$W_{inj} = 1005 - 55 = 950 \text{ lb (nominal)}$$

A $\pm 5\%$ variation in payload capability is believed appropriate, based on this study estimate.

$$W_{inj} = 900 \text{ to } 1,000 \text{ lb}$$

2. Trajectory Considerations

The lunar injection schemes of the *Atlas-Agena* and the *Atlas-Centaur* boosters are essentially the same as far as the spacecraft is concerned. Both are designed to use a parking orbit with a 60- to 90-hr transit time and both also require (1) a self-contained orientation and attitude control system within the spacecraft for coasting flight and (2) a small midcourse maneuver for injection inaccuracy correction.

Since the 1σ injection errors of the *Atlas-Agena* (60 ft/sec) are roughly twice those predicted in the *Atlas-Centaur* booster (30 ft/sec), the vernier-system propellant requirements are twice that for the *Surveyor* on a spacecraft percentage basis. This increases the total spacecraft vernier impulse and burning time slightly, which should be considered in the vernier design but presents no serious problem.

⁴The current flight payload capability of the *Atlas D-Agena B* for *Ranger* flights RA 6 through 8 is 958 lb min, including spacecraft support equipment.

3. Design Considerations

Since the *Atlas-Agena* and *Atlas-Centaur* have similar booster-to-spacecraft integration approaches, there seem to be no unique problems involved in introducing a *Surveyor*-type spacecraft on the *Atlas-Agena* booster from the standpoint of the design. The spacecraft installation in the *Agena* nose shroud is shown in Fig. 1. This design uses the same space envelope currently adopted for the *Mariner C* spacecraft. The inverted configuration was adopted since the shroud clearance and spacecraft support problems seemed to be improved and it did not introduce any new booster or spacecraft problems. This inverted position does require an increase in complexity for the initial orientation maneuver of the

spacecraft after separation; however, this seems to be within the capabilities of the current *Surveyor* orientation system. In the inverted position, the spacecraft landing legs lend themselves to a simple 3-point support and separation scheme. This results in a 15-lb weight savings compared to the 70-lb *Mariner C* type of spacecraft-support equipment. The dynamic characteristics of this support scheme do present a problem, however. Preliminary estimates of the natural frequency of this payload are in the 10-cps range. Although this is somewhat removed from the primary structural bending mode, the fuel sloshing and motor gimbaling frequencies of the booster system, it is low enough to cause concern and should be reviewed.

IV. SPACECRAFT DESIGN

The design developed for the MSL is shown in Figs. 1 through 4. This design consists of modified *Surveyor* guidance and control systems, repackaged with scaled-down *Surveyor*-type propulsion into a compact structural configuration. This design was dictated by the adoption of the *Surveyor* spacecraft approach in order to minimize the development program of the MSL. The high degree of similarity achieved between the MSL and *Surveyor* is shown in Appendix A, which compares the flight sequence of operations of the two spacecraft. Obviously, the two major flight phases of the spacecraft are essentially identical. Both spacecraft are Sun-oriented, and both use solar power and perform a midcourse maneuver using the vernier propulsion system in the coasting phase of flight. The lunar landing phase of the two spacecraft uses the same unique guidance and propulsion scheme for the retro maneuver that is incorporated in *Surveyor*.

Although the subsystem approach of the two spacecraft is almost identical, the structural configurations are considerably different. This difference results from booster shroud constraints. The *Centaur* shroud forced a packaging of the spacecraft around the main retro propulsion in *Surveyor*, making for a low-density spacecraft. However, these restraints are less critical on the *Atlas-Agena*, because the spacecraft is reduced in size. This results in a separate spacecraft and main retro propulsion design, which is a more efficient approach.

This new spacecraft consists of a thermally controlled center box (electronic equipment compartment) which also serves as the structural frame. The three attached legs support the center box during boost, as well as during landing operations. They also house the scaled-down *Surveyor*-type vernier propulsion system. Hinged, crushable landing pads permit vernier operation during the

midcourse and lunar descent conditions. The solid-propellant, main retro motor, which is a scaled-down *Surveyor* type of motor, is attached to the lower deck of the center box and contains the *Surveyor* altitude-marking radar in the nozzle. Other *Surveyor* flight sensors are mounted on the sides of the center box, including solar, Canopus, and doppler-velocity radar equipment. The top deck of the center box supports a fixed solar panel and a TV camera. The solar panel, which is in the shape of an annular array, only provides power during the flight operations. Batteries are provided for the TV and other experiment equipment after landing. Slow playback of scientific information is obtained through the two omniantennas; the minimum life of the spacecraft after landing is of the order of $\frac{1}{2}$ to 1 hr. The maximum life could be considerably longer if the lunar thermal environment is favorable and the landed position permits battery recharging by the fixed solar panels.

As is evident, the spacecraft design, as developed, has emphasized the minimal approach to accomplish this mission. This is, of course, a result of the critical payload restraint established by the booster. For this reason, particular attention was placed on obtaining a realistic weight estimate of the injected spacecraft. Results of this effort are summarized in Table 2, which presents the weights of the major spacecraft systems.

This estimate was obtained by reviewing a detailed list of subsystem parts of the *Surveyor* (Appendix B) with responsible engineers from Hughes and JPL. Estimates were then made of the weight differences resulting from the changes necessary to convert to MSL equipment. It is believed that this approach afforded a high degree of realism about the weight estimates of this study. For this reason, a 10% contingency in spacecraft hardware weights was considered appropriate to assure an adequate estimate for booster payload injection requirements.

Table 3 presents the comparative weight summary of the MSL and *Surveyor* systems, together with remarks concerning the differences. A more complete review of these subsystems and their problem areas, including a detail weight comparison of the MSL and equivalent *Surveyor* components, is in the following discussion.

A. Flight Controls Group

The functions of the MSL controls group, as well as a majority of the critical components of the MSL, are identical to those of the *Surveyor*. This group is responsible for maintaining the correct attitude of the spacecraft during the various phases of the separated flight. These include:

Table 2. Weight summary of the MSL spacecraft

System	Spacecraft weight (landed), lb	Spacecraft weight (injected), lb
Flight control	35.9	35.9
Electronics	51.5	58.9
Electrical power	18.5	18.5
Mechanisms	3.7	3.7
Spacecraft vehicle	79.2	79.2
Propulsion		
Vernier system hardware	31.9	31.9
Vernier propellant		69.1
Main retro hardware	3.7	54.8
Main retro propellant		498.0
Payload		
TV experiment	10.0	10.0
Surface-hardness experiment	10.0	10.0
Experiment power	15.0	15.0
Spacecraft weight, total	259.4	
Injected weight, total		885.0
Contingency 10%	25.9	88.5
Total	285.3	973.5

1. Acquiring and maintaining Sun orientation of the spacecraft after injection and during coasting flight.
2. Rotating the spacecraft to the appropriate attitude to perform midcourse and lunar retro maneuvers (prior to vernier and main retro propulsion operations).

The group consists of a number of sensor subsystems that establish the desired maneuver and an attitude control system which performs the maneuver. A detailed list of the components and their weight is presented in Table 4. Reasons for the differences are noted in the Remarks column.

The large reduction in the MSL attitude control system weights as compared to *Surveyor* is a direct result of change in moments of inertia of the two spacecraft. However, although the moments of inertia differ by a factor of approximately 4, the component weights differ only by a factor of 1.5 because of fixed losses of attitude gas that are caused by limit cycling and minimum tolerance effects.

It should be noted that the structural factors of safety have been reduced from 2.2 (man-rated) to 1.25 in the

Table 3. Comparative injected weight summary of the MSL and Surveyor

System	MSL, lb	Surveyor, lb	Remarks
Flight controls	35.90	52.17	Sensor package supported in center box. Also reduced attitude control requirements for smaller spacecraft.
Electronics	58.90	93.25	Reduced experiment requirements. Also removed redundant communications components.
Electrical power	18.50	54.50	Reduced experiment power (batteries).
Mechanism	3.69	29.79	Reduced experiment requirements (no active high-gain antenna or solar panel).
Spacecraft vehicle	79.14	196.70	Reduced mission. New structure configuration.
Propulsion			
Vernier system	31.87	74.99	Reduced spacecraft weight.
Vernier propellant	69.10	154.30	Reduced spacecraft weight.
Main retro hardware	54.80	141.34	Reduced spacecraft weight.
Main retro propellant	498.00	1196.40	Reduced spacecraft weight.
Payload	35.00	124.00	Reduced mission.
Total	865.00	2117.44	
Contingency	88.50	0	
Total injected	973.5	2117.44	

Table 4. Weight breakdown of flight controls

Component	MSL, lb	Surveyor, lb	Remarks
Sensor group			Identical
Inertial reference unit	7.90	7.90	
Canopus sensor	4.80	4.80	Identical
Wiring harness (switch and mounting and accelerometer and mount, primary solar sensor, circuitry)	1.02	1.02	Identical sensors — new wiring
Electronics, flight control	12.40 ^a	19.10	Improved Surveyor design
Support and hardware	1.00	2.38	New supports
Sensor, solar secondary	0.35	0.35	Identical
Subtotal	27.47	35.55	
Attitude control system group			
Jets	1.12	1.62	Same design — reduced size
Tank	2.65	7.4	Same design — reduced size
Pressure control	1.15	1.90	Same design — reduced size
Actuator, roll vernier jet	1.00	1.20	Same design — reduced size
Nitrogen gas	2.50	4.5	Same design — reduced size
Subtotal	8.42	16.62	
Total, both groups	35.89	52.17	

^aThe proposed Hughes redesign for Surveyor reduces this weight 5.0 lb.

interest of performance improvements. This results in a more complex ground pressurization system (on the gantry). However, the additional performance is considered worth the complication.

B. Electronics

This group includes spacecraft communications and command control as well as the altitude and velocity-sensor systems for the soft-landing maneuvers. The functions and a majority of the critical components and their weights are presented in Table 5. *Surveyor* weights, together with an explanation of the differences, are also shown.

The entire radar altimeter and doppler velocity sensor under development for *Surveyor* were adopted in this study to provide spacecraft altitude, attitude, and velocity information to the flight-control system during the final descent portion of the lunar landing phase of the mission. The extension of the original *Surveyor* concept

of doppler attitude control during the 5-ft/sec constant-velocity descent, which is being investigated, seems appropriate for providing improved landing dynamics for the MSL. The advantage of using doppler attitude control during the constant-velocity descent is a reduction in lateral velocity. This reduction is achieved at the expense of increased sensitivity of spacecraft attitude to radar noise because of the higher system gain required to maintain stability. Any relaxation of the radar noise requirement depends on a tradeoff between spacecraft attitude and lateral velocity, with landing dynamics and stability as the criteria. The performance of the doppler sensing system prior to dropping of the main retro propulsion stage will require additional investigation because of the aggravated interference problem presented by the main retro position.

The altitude-marking radar, as developed for *Surveyor*, is also directly applicable in a light-weight lander. It indicates the proper spacecraft-to-lunar-surface slant range for firing the retro engine. The radar employs pulse modulation of transmitted microwave energy in

Table 5. Weight breakdown of electronics system

Item	MSL, lb	Surveyor, lb	Remarks
2 omni-antennae	1.00	1.00	Revised geometry
RF switches	1.00	1.25	Identical — removed redundancy
Transmitter	6.46	12.95	Identical — removed redundancy
Command receiver transponder	3.47	6.94	Identical — removed redundancy
Central command decoder	1.95	5.45	Same design — reduced requirements
Central signal processor	3.55	5.25	Same design — reduced requirements
Doppler velocity sensor-altimeter	24.82	27.32	Identical — improved supports
Power-control system B	4.50	8.80	Same design — reduced requirements
Engineering signal processor B	3.50	6.15	Same design — reduced requirements
Mechanical auxiliaries A	1.22	2.27	Same design — reduced requirements
Thermal control	0.20	0.20	Identical
Total (soft-landed)	51.47	86.05	
Downward TV	0	7.20	Not required for MSL
Total (soft-landed)	51.47	93.25	
Altitude-marking radar	7.40	8.50	Identical — weight estimate conservative
Total (injected)	58.87	101.75	

which the transit time of the return signal is compared to a predetermined delay. This delay, as presently set up, corresponds to a slant range of 56 mi. A more appropriate slant range may be in order for the light-weight lander after detailed analysis of the retro/vernier capabilities. Different slant ranges would be accommodated by changes in the delayed gate.

The telecommunications makes use of the transmitter and receiver developed for the *Surveyor*, but for the purpose of this study redundancy has been eliminated and only one transmitter and one receiver have been incorporated. On-board radio reception, demodulation, modulation, and transmission necessary for doppler frequency and angle tracking by the DSIF during the transit phase will be implemented through techniques developed for the *Surveyor*.

C. Electrical Power

This group provides electrical power for the various spacecraft systems during the flight and for the landed phase of the mission. The function of the MSL group, which consists of batteries and solar panels, is again essentially identical to that of *Surveyor*. However, because of the reduced science mission, solar power is not required after landing. As a result, the solar panels are fixed on the MSL spacecraft. During the transit phase, the Sun sensor generates error signals, and the attitude control system orients the spacecraft so that the solar-cell panel faces toward the Sun. This provides power for the majority of the coasting flight requirements. Prior to landing, the batteries will be in a sufficiently charged condition to transmit the TV pictures after landing. However, if the landed position of the spacecraft is in a favorable environment, supplementary solar power will be available after landing. Additional weight savings could be realized by using "hot shot" batteries. A detailed list of the components and their weights is presented in Table 6. *Surveyor* equivalents are shown for comparison.

Table 6. Weight breakdown of electrical power

Item	MSL, lb	Surveyor, lb	Remarks
Solar panel	8.50	8.5	Repackaged
Batteries	10.00 ^a	46.00	Reduced requirements
Total	18.5	54.5	

^aThese, as well as 15 lb of additional experiment batteries, are used by the science payload.

Reasons for the differences are noted in the Remarks column.

D. Mechanisms

This group consists of positioning mechanisms required as a result of geometric constraints. On *Surveyor*, these are essentially associated with antennas and solar-panel positioners. However, with the absence of the movable high-gain antenna and solar panels on the MSL, very few such mechanisms are required. The detailed list of the MSL mechanism and their weights is presented in Table 7. *Surveyor* weights are indicated for comparison.

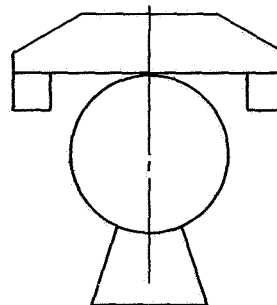
Table 7. Weight breakdown of mechanisms

Item	MSL, lb	Surveyor, lb	Remarks
Omni-antenna No. 1 actuator	1.28	2.28	Improved support
Omni-antenna No. 2 actuator	0.75	1.26	Improved support
Separation sensor and arm	1.65	1.65	Same design
Subtotal	3.69	5.19	
Solar and high-gain antenna actuators	0	24.6	Not required for MSL
Total	3.69	29.79	

As is evident, the weight difference is essentially due to the removal of actuated solar and antenna arrays.

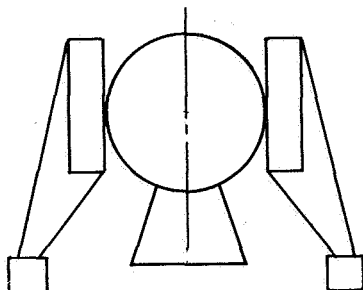
E. Spacecraft Vehicle

This group consists essentially of the spacecraft structure. Although it accomplishes the same function in the MSL and the *Surveyor*, the designs are quite different as a result of difference in mission as well as difference in booster shroud constraints. The MSL spacecraft structure uses a separated configuration (see Sketch A) which



Sketch A

has a compact landing spacecraft on top of the main retro motor. The *Surveyor*, however, uses an integrated design (see Sketch B) which packages the spacecraft around the main retro motor. This results in a lower-density spacecraft with a high center of gravity, which requires large, folding landing legs.



Sketch B

The separated MSL design consists of a center box which houses the electronic equipment. The spacecraft is supported by the landing legs during boost and during the lunar landing phase. The design permits the use of these two components for the basic spacecraft structure, whereas the integrated design requires a separate vehicle structure. The effect of this difference in configurations is shown in Table 8. *Surveyor* weights are presented for comparison.

As may be seen in Table 8, the new configuration results in a considerable amount of development effort for these spacecraft components. However, the major effort is concentrated on conventional design, which should present no new problems.

The central box (Fig. 5) consists of fiberglass honeycomb panel sides and bottom deck with a metal top deck. These provide structural support for the internal equipment and for the landing legs as well as an appropriate thermal environment for sensitive internal components during flight and landing conditions.

The temperature-control problem of this box is of considerable interest. Because of the relatively straightforward thermal-design conditions of the MSL as compared with the *Surveyor* (i.e., reduced lunar lifetime requirement), a passive system was considered adequate. However, the thermal design of the central box uses the approach taken for the *Surveyor* equipment box. The insulating sides and bottom minimize heat transfer during the flight phases, while the metal top deck, treated with appropriate thermal coatings, provides the neces-

Table 8. Weight breakdown of spacecraft vehicle

Item	MSL, lb	<i>Surveyor</i> , lb	Remarks
Basic structure	0	56.97	Integrated into compartments and landing gear
Landing gear	20.00	39.09	Simplified design for reduced size
Compartments	30.00	43.18	Reduced mission and no redundancy
Hardware	12.05	21.86	New design for reduced size
Paint	0.50	1.00	New design for reduced size
Wiring	13.00	28.81	New design for reduced size
Attitude control lines	0.44	0.84	New design for reduced size
Retro release	1.21	1.71	Reduced size
Engineering sensors	1.00	2.34	Reduced requirements
Agona B latches	0.90	0.90	Same design
Total	79.14	196.70	

sary heat transfer to maintain acceptable temperatures. These same insulating sides and bottom minimize heat transfer from the lunar surface into the box in the landed condition. This lengthens the thermal transient which heats up the box after landing. The length of this transient is believed adequate to provide the 1/2- to 1-hr lifetime considered necessary to complete the mission.

The propulsion thermal controls are essentially the same as for *Surveyor*, using passive controls (coatings, blankets, etc.).

The fixed landing legs are of conventional aluminum (or fiberglass) structure with crushable *Surveyor*-type landing pads to limit landing load. These pads are hinged to permit vernier motor operation, which continues to within 15 ft of lunar surface. At this time, the vernier motors shut off (similar to *Surveyor*) and the spacecraft drops to the surface. During this period (approximately 2 sec), the spring-loaded hinged pads are released to rotate to the landing position.

F. Propulsion

The functions and mechanization of the propulsion system in the MSL and the *Surveyor* are identical. As a

result, the profiles of the descent trajectories are similar. The monomethyl-hydrazine vernier propulsion system provides the midcourse impulse in both of the spacecraft, and it maintains attitude control during the landing phase. The main solid retro then provides the major portion of the lunar landing impulse. However, since the smaller MSL spacecraft requires only 45% (approximately) of the *Surveyor* impulse, a complete redesign of the propulsion system components is necessary. The major problems resulting from this propulsion redesign are discussed below.

1. Main Retro Propulsion

The scaling down of the *Surveyor* 37-in.-D solid retro motor by 55% represents an appreciable development effort. However, there should be no particular new development problems since a motor of this reduced size (approximately 25-in.-D) has already been partially developed. This motor, with performance roughly comparable to the *Surveyor* motor, was developed (test fired three times) for a propulsion program approximately 2 yr ago. It should be noted that considerable additional testing will be necessary in order to establish flight-quality motors, particularly since the motor hardware will require considerable redesign to meet MSL requirements. The necessary hardware changes would include a revised nozzle for increased expansion ratio, closer chamber and nozzle tolerances for thrust alignment requirements, and revised support structure.

One of the fundamental consequences of scaling down soft-landing spacecraft using spherical motors is a change in burning time t_b and in acceleration a .

Since the retro impulse I is directly proportional to the spacecraft weight W , the scaling factor f is:

$$\frac{I_2}{I_1} = \frac{W_2}{W_1} = f$$

Since the motor diameter varies as the cube root of total impulse (volume relationship),

$$\frac{D_2}{D_1} = \left(\frac{I_2}{I_1} \right)^{1/3} = f^{1/3}$$

Since burning time varies linearly with diameter (web fraction),

$$\frac{t_{b2}}{t_{b1}} = \frac{D_2}{D_1} = f^{1/3}$$

The spacecraft acceleration is then

$$a = \frac{F}{W} = \frac{I}{W t_b}$$

The acceleration ratio between two spacecraft due to scaling is then

$$\begin{aligned} \frac{a_2}{a_1} &= \left(\frac{W_2}{W_1} \right) \left(\frac{t_{b1}}{t_{b2}} \right) \left(\frac{I_2}{I_1} \right) \\ &= \left(\frac{1}{f} \right) \left(\frac{1}{f} \right)^{1/3} (f) = \left(\frac{1}{f} \right)^{1/3} \end{aligned}$$

Since the scaling factor between the MSL and the *Surveyor* is

$$f = \frac{947}{2100} = 0.45$$

the ratio of accelerations during descent is

$$\frac{a_{(MSL)}}{a_{(Surv)}} = \left(\frac{1}{0.45} \right)^{1/3} = 1.30$$

The 30% increase in acceleration of the MSL causes the following problems:

1. Increased structural requirements during descent⁵
2. Changes to the vernier propulsion thrust level and impulse requirements for attitude control during descent
3. Increased efficiency of the retro propulsion (reduced results in a slightly higher payload)
4. Reduced attitude of marking-radar actuation

In general, these do not present any new development problems; however, they will require detailed investigation. Table 9 lists main retro components and their weights. *Surveyor* weights are presented for comparison.

2. Vernier Propulsion System

Throttleable attitude control systems using chemical propellants are an advanced development in the rocket propulsion field. *Surveyor*, which is the first spacecraft to adopt this approach, is currently having difficulties with this system. These problems are associated with the

⁵Landing impact conditions are generally more critical.

Table 9. Weight breakdown of main retro propulsion

Main retro hardware	MSL, lb	Surveyor, lb	Remarks
Engine	47.00	131.50	Same design — reduced size
Insulation	3.50	5.54	Same design — reduced size
Igniter	0.60	0.60	Same design
Subtotal	51.10	137.64	—
Main retro arming	3.7	3.7	Identical
Total	54.8	141.34	—
Main retro propellant	498.0	1,196.4	Same design — reduced size

use of regeneratively cooled motors. Difficulties are encountered in providing adequate cooling for (1) the minimum thrust requirements in the chamber due to heat capacity limitations and (2) transient heating problems in the vicinity of the nozzle on abrupt thrust changes of large magnitudes. Unfortunately, both of these problems, minimum thrust and high-throttle ratio, are aggravated by scaling down to MSL conditions. The minimum thrust is set by hovering requirements and by slow descent for final touchdown conditions. The minimum thrust level $T_{V \min}$, therefore, scales linearly with weight or scale factors. The ratio of the T_{\min} of the MSL and the *Surveyor* is then

$$\frac{T_{V \min(\text{MSL})}}{T_{V \min(\text{Surv})}} = \frac{W_{\text{Surv}}}{W_{\text{MSL}}} = f$$

The maximum thrust level is set by the attitude control moment requirements during the main retro operation. In other words, the pitching moment due to the misalignment between the main retro thrust and the spacecraft center of gravity must be balanced by the moment due to the differential thrust of the vernier motors. Therefore

$$T_{V \max} l_v = T_R l_R$$

where

$T_{V \max}$ = maximum thrust of vernier motors

T_R = maximum thrust of solid retro

l_v = vernier motor moment arm

l_R = moment arm between retro and center of gravity

and

$$T_{V \max} = \frac{l_R}{l_v} T_R$$

Considering the effect of scaling on $T_{V \max}$, the T_R scaling effect is

$$\frac{T_{R2}}{T_{R1}} = \frac{a_2 W_2}{a_1 W_1} = \left(\frac{1}{f}\right)^{1/3} \quad f = f^{2/3}$$

And since geometric scaling is

$$\frac{l_R}{l_v} = \frac{f}{f} = 1^\dagger$$

Then the maximum vernier thrust due to scaling is

$$T_{V \max} = f^{2/3}$$

and the effect on the vernier throttle ratio T_{VT} due to scaling is

$$T_{VT} = \frac{T_{V(\max)}}{T_{V(\min)}} = \frac{f^{2/3}}{f} = \left(\frac{1}{f}\right)^{1/3}$$

The minimum thrust required for the MSL verniers⁶ is then

$$T_{V \min(\text{MSL})} = 0.45 T_{V \min(\text{Surv})} = 0.45(30) = 13.5 \text{ lb}$$

The throttle ratio⁷ required is

$$\begin{aligned} T_{VT(\text{MSL})} &= \left(\frac{1}{f}\right)^{1/3} T_{VT(\text{Surv})} \\ &= \left(\frac{1}{0.45}\right)^{1/3} (3.5) = 4.55 \end{aligned}$$

The thrust reduction to 45% of *Surveyor* vernier size, plus the throttle ratio increase of 30% required by the MSL, made the use of regeneratively cooled motors look considerably more difficult on the MSL. Since ablatively cooled motors developed by industry have demonstrated

[†]This applies adequately to the *Surveyor* and MSL design for a first approximation.

⁶*Surveyor* minimum thrust is 30 lb.

⁷*Surveyor* throttle ratio is 3.5.

the ability to meet all the vernier performance requirements (including the throttling ratio and low thrust level conditions), the *Surveyor* spacecraft is currently considering adopting this scheme. This approach should also be investigated for the MSL.

Scaling of the remainder of the vernier system represents considerable effort; however, it presents no major difficulty. A list of the components and their weights is presented in Table 10. *Surveyor* weights are listed for comparison.

Table 10. Weight estimate of vernier propulsion system

Vernier wgt, landed	MSL, lb	Surveyor, lb	Remarks
He valve	1.50	1.93	Same design — reduced size
He tank	3.78	20.31	Same design — reduced size and modified operations
Fuel tanks	3.75	9.75	Same design and reduced size
Oxidizer tanks	3.72	9.72	Same design and reduced size
Thrust chambers	10.00	17.09	Same design and reduced size
Thermal control	2.95	5.65	Same design and reduced size
Lines and manifold	3.34	4.84	Same design and reduced size
Helium	0.83	2.50	Same design and reduced size
Unusable propellant	2.00	3.20	Same design and reduced size
Total	31.87	74.99	
Vernier propellant	69.1	154.3	Reduced size

V. EXPERIMENTS

The primary experiments considered for the first MSL payload are concerned with providing soft-landing technology and lunar environment information for the manned lunar program. This includes TV photos and soil-hardness measurements. Table 11 lists the component weights of this group, along with equivalent *Surveyor* weights for comparison.

Table 11. Weight breakdown of scientific experiments

Item	MSL, lb	<i>Surveyor</i> , lb	Remarks
TV camera and equipment	10.0	17	Simplified <i>Surveyor</i> camera
Soil mechanic equipment	10.0	16	Same equipment — reduced size
Batteries	15.0 ^a	46	Reduced science mission
Additional experiments	0	45	Reduced science mission
Total	35	124	
^a Approximately 10 lb of additional batteries are used for in-flight operations. These are also available (in partially recharged condition) for experiments after landing.			

The TV camera and mechanization is placed on top of the spacecraft in order to provide gross and local terrain coverage. (Stereo could be obtained by one additional positioning mechanism which would pivot the camera about its vertical centerline.)

The telecommunications and power supply have been sized for transmitting slowscan TV pictures after landing. A 200-line TV system provides 360-deg coverage of the landing site with eight overlapping TV frames. The frames are transmitted through the omni-antenna system over a period of approximately 5 min, and the sequence continues until depletion of the power supply. The transmitter receives video signals and generates a modulated voltage at 19.125 mc. The modulated power is then amplified and multiplied to a 100 mw at 2295 mc by means of solid-state circuitry. This output is radiated directly through the omni-antenna system, but normally it is switched into the path of a traveling-wave tube amplifier and radiated at a 10-w power level.

A further reduction of injected weight could be accomplished by using a TV system less sophisticated than the *Surveyor* approach. A slow-scan facsimile system would reduce telecommunications and power requirements. Touchdown pictures could not be provided with this system.

In general, additional experiments can be located within the center box for thermal control and protection on landing, or they can be mounted externally on the box sides. The soil-hardness experiment is mounted on the side. It is a miniaturized version of the *Surveyor* soil-mechanics instruments, which consists of two fixed-size penetrometers which provide load-deflection information as they are pressed into the surface soil. Data is then transmitted through the spacecraft omni-communications systems.

APPENDIX A

Comparative Sequence of Flight Operations for Surveyor and MSL

Time (Approximate)	Surveyor operation	MSL operation
0 min, 0 sec	Launch	Same
+3 min, 20 sec	Eject shroud	Same
+26 min, 5 sec	Extend landing-gear signal	None
+26 min, 55 sec	Extend omnidirectional antenna signal	Same
+27 min, 14 sec	Separation of spacecraft from Centaur; Centaur retro-maneuver	Same with Agena
Varies	Acquisition of spacecraft by DSIF	Same
+38 min, 54 sec	Command engineering data mode 1 and observe gyro error and precision command signals	Same
+39 min, 24 sec	Command unlocking of solar panel	None
+39 min, 34 sec	Step solar panel to its transit position	None
+48 min, 49 sec	Command Sun-acquisition mode on	Same
+1 hr, 1 min, 0 sec	Command star-acquisition mode on (Canopus)	Same
+1 hr, 14 min, 5 sec	Command engineering data mode 4 and observe power parameters and temperatures	Same
+2 hr, 30 min	SFOF completes first orbit determination	Same
+6 hr, 30 min	SFOF completes second orbit determination	Same
+8 hr, 32 min	Command radiation detector power to conduct 1-hr radiation detection experiment. Range from Earth is approximately 10,000 km.	None
+19 hr, 30 min	SFOF computes required midcourse correction maneuver and transmits command information to Goldstone	Same
+20 hr, 17 min	Perform premidcourse correction maneuver to establish attitude of spacecraft so that velocity can be imparted in proper direction to ensure accurate landing on Moon.	Same
+20 hr, 32 min	Command execute velocity increment magnitude	Same
+20 hr, 33 min	Command reverse pitch maneuver and lock on Sun	Same
+20 hr, 40 min	Command reverse roll maneuver and lock on Canopus Periodic engineering interrogation of spacecraft	Same
+59 hr, 30 min	Terminal maneuver computations performed by SFOF determine maneuver angles for spacecraft, proper time for triggering marker radar, proper main retro-engine ignition delay	Same
+64 hr, 41 min	Command deployment of planar array to its landing position	None
+64 hr, 52 min	Command execute attitude maneuver to align thrust vector with velocity vector	Same
+64 hr, 55 min	Command execute roll maneuver to point planar array toward Earth	None
+65 hr, 3 min	Command start camera No. 4 (downward looking) TV pictures. Sequence is 10 TV pictures followed by 5 sec mode 2 engineering data at various intervals until 4 min before touchdown	None
+65 hr, 15 min (110 \pm 4.5 mi to Moon)	Trigger marking radar, starting main retro-timer and vernier engine operation at previously commanded thrust bias level and turning on doppler and altimeter radars.	Same
+65 hr, 15 min, 44 sec	Main retro-ignition commanded by timer. Marker radar is blown away.	Same

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Time (Approximate)	Surveyor operation	MSL operation
+65 hr, 15 min, 54 sec	Attempt to obtain 2 TV pictures during retro burning period	Same
+64 hr, 16 min, 31 sec	Main retro-burnout and increase vernier thrust level	Same
+65 hr, 16 min, 39 sec	Main retro-case injection. Initiate altitude programmed thrust mode when reliable doppler and altitude signal is present	Same
+65 hr, 18 min, 6 sec	Observe 1000-ft signal	Same
+65 hr, 18 min, 34 sec	Observe 10-ft/sec signal	Same
+65 hr, 18 min, 42 sec	Vernier engines turned off. Observe 13 ft altitude signal	Same
+65 hr, 18 min, 44 sec	Touchdown	Same
+66 hr	Initiate lunar sequence	Same

APPENDIX B

Weight Data for Surveyor and MSL^a

Code	Item	Drawing No.	Surveyor ^b , lb	MSL, lb
5 0	Spacecraft gross		2123.44	884.80
6 1	Nitrogen		-2.50	1.50
6 0	Before retro ignition		2120.94	883.31
7 1	Igniter, pyrogen ^b		-0.60	0.60
7 2	Retro-propellant ^b		-1196.40	498.00
7 3 1	Fuel — vernier		-2.97	1.22
7 3 2	Fuel — vernier		-2.97	1.22
7 3 3	Fuel — vernier		-2.97	1.22
7 3 4	Oxidizer — vernier		-4.45	1.83
7 3 5	Oxidizer — vernier		-4.45	1.83
7 3 6	Oxidizer — vernier		-4.45	1.83
7 4 1	Radar altimeter marking ^b		-8.30	7.40
7 4 2	Insulation ^b		-0.76	0.76
7 0	After retro-ignition		892.62	367.40
8 1	Retro main engine ^b	238608	-131.50	47.0
8 2	Insulation — retro engine		-5.54	3.50
8 3 1	Fuel — vernier		-1.11	0.47
8 3 2	Fuel — vernier		-1.11	0.47
8 3 3	Fuel — vernier		-1.11	0.47
8 3 4	Oxidizer — vernier		-1.67	0.70
8 3 5	Oxidizer — vernier		-1.67	0.70
8 3 6	Oxidizer — vernier		-1.67	0.70
8 0	After retro separation		747.24	313.39
9 1 1	Fuel — vernier		-4.72	1.97
9 1 2	Fuel — vernier		-4.72	1.97
9 1 3	Fuel — vernier		-4.72	1.97
9 1 4	Oxidizer — vernier		-7.08	2.96
9 1 5	Oxidizer — vernier		-7.08	2.96
9 1 6	Oxidizer — vernier		-7.08	2.96
9 0	Maximum touchdown weight		711.84	298.53
10 1	Residual helium		-2.50	0.83
10 2	Residual nitrogen		-2.00	1.00
10 3 1	Residual vernier fuel		-11.72	5.96
10 3 2	Residual vernier fuel		-11.72	5.96

^a Maximum touchdown weight condition.^b As of 1-25-63.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
10 3 3	Residual vernier fuel		-11.72	5.96
10 3 4	Residual vernier oxidizer		-17.57	8.95
10 3 5	Residual vernier oxidizer		-17.58	8.95
10 3 6	Residual vernier oxidizer		-17.58	8.95
10 0	Spacecraft dry weight		619.45	252.07 ^b
5 0	Spacecraft gross		2123.44	884.80
11 1	Nitrogen		-4.50	2.50
11 3 1	Fuel — vernier		-2.92	2.40
11 3 2	Fuel — vernier		-2.92	2.40
11 3 3	Fuel — vernier		-2.92	2.40
11 3 4	Oxidizer — vernier		-4.37	3.61
11 3 5	Oxidizer — vernier		-4.37	3.61
11 3 6	Oxidizer — vernier		-4.37	3.61
11 0	Before retro ignition		2097.07	863.74
12 1	Igniter, pyrogen ^a		-0.60	0.60
12 2	Retro propellant ^a		-1196.40	498.00
12 3 1	Fuel — vernier		-4.36	1.75
12 3 2	Fuel — vernier		-4.36	1.75
12 3 3	Fuel — vernier		-4.36	1.75
12 3 4	Oxidizer — vernier		-6.54	2.62
12 3 5	Oxidizer — vernier		-6.54	2.62
12 3 6	Oxidizer — vernier		-6.54	2.62
12 4 1	Radar altimeter marking ^a		-8.30	7.40
12 4 2	Insulation ^a		-0.76	0.76
12 0	After retro ignition		858.31	343.87
13 1	Retro main engine ^a	238608	-131.50	47.0
13 2	Insulation — retro engine ^a		-5.54	3.50
13 3 1	Fuel — vernier		-1.29	0.52
13 3 2	Fuel — vernier		-1.29	0.52
13 3 3	Fuel — vernier		-1.29	0.52
13 3 4	Oxidizer — vernier		-1.94	0.79
13 3 5	Oxidizer — vernier		-1.94	0.79
13 3 6	Oxidizer — vernier		-1.94	0.79
13 0	After retro separation		711.58	289.44

^aAs of 1-25-63.

^bDry weight = landed weight (helium + nitrogen + unusable propellant)
= 259.4 - (0.83 + 2.5 + 2) = 252.07.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
14 1 1	Fuel — vernier		-11.52	4.70
14 1 2	Fuel — vernier		-11.52	4.70
14 1 3	Fuel — vernier		-11.52	4.70
14 1 4	Oxidizer — vernier		-17.29	7.05
14 1 5	Oxidizer — vernier		-17.29	7.05
14 1 6	Oxidizer — vernier		-17.29	7.05
14 0	Minimum touchdown weight		625.15	254.19
15 1	Helium		-2.50	0.83
15 2 1	Unusable vernier fuel		-0.43	0.17
15 2 2	Unusable vernier fuel		-0.43	0.17
15 2 3	Unusable vernier fuel		-0.43	0.17
15 2 4	Unusable vernier oxidizer		-0.63	0.26
15 2 5	Unusable vernier oxidizer		-0.64	0.26
15 2 6	Unusable vernier oxidizer		-0.64	0.26
15 0	Spacecraft dry weight		619.45	252.07 ^b
1 0	Basic bus L retro		505.10	
1 1	Flight-control system		52.17	33.9
1 1 1	Sensor group	235000	35.20	25.47
1 1 1 1	Inertial reference unit	235100	7.90	7.9
1 1 1 2	Canopus sensor	235300	4.80	4.8
1 1 1 3	Wiring harness	235005	1.02	1.02
1 1 1 3 1	Switch + mounting	260460	0.17	0.17
1 1 1 3 2	Accelerometer + mounting		0.21	0.21
1 1 1 3 3	Sensor, solar primary	235400	0.36	0.36
1 1 1 3 4	Circuitry		0.28	0.28
1 1 1 4	Electron — flight control		19.10	10.40
1 1 1 5	Support + hardware	235006	2.38	1.00
1 1 2	Sensor, solar secondary		0.35	0.35
1 1 3	Attitude control system		16.62	8.42
1 1 3 1	Attitude jets		1.62	1.12
1 1 3 1 1	Attitude jet, LDG No. 1	235700	0.54	0.37
1 1 3 1 2	Attitude jet, LDG No. 2	235700	0.54	0.37
1 1 3 1 3	Attitude jet, LDG No. 3	235700	0.54	0.37
1 1 3 2	Gas supply		9.30	8.42

^aAs of 1-25-63.

^bDry weight = landed weight (helium + nitrogen + unusable propellant)
= 259.4 - (0.83 + 2.5 + 2) = 252.07.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 1 3 2 1	Nitrogen gas tank		7.40	2.65
1 1 3 2 1 1	Tank	235606	7.30	2.55
1 1 3 2 1 2	Paint		0.10	0.05
1 1 3 2 2	Pressure control		1.90	1.15
1 1 3 3	Actuator, roll vernier jet	235200	1.20	1.00
1 1 3 4	Nitrogen		4.50	2.50
1 2	Electronics		93.25	58.87
1 2 1	Data link		30.61	
1 2 1 1	Antenna planner array	232300	8.50	0
1 2 1 2	Antenna omni-directional 1	232400	0.50	0.5
1 2 1 3	Antenna omni-directional 2	232400	0.50	0.5
1 2 1 4	RF transmitter sw A	232550	0.75	0.50
1 2 1 5	RF transmitter sw SPDT A	232560	0.50	0.50
1 2 1 6	Transmitter A A	231800	6.46	6.46
1 2 1 7	Transmitter B A	231800	6.46	0
1 2 1 8	CMD receiver-transponder A A	231900	3.47	3.47
1 2 1 9	CMD receiver-transponder B A	231900	3.47	0
1 2 2	Central command decoder B	23200	5.45	1.95
1 2 3	Central signal processor B	232200	5.25	3.55
1 2 4	Doppler velocity sensor-altimeter	232800	27.32	24.82
1 2 4 1	Signal data converter	232903	8.85	—
1 2 4 2	Klystron power support	232904	7.86	—
1 2 4 3	Antenna — altitude/velocity sensor	232905	5.18	—
1 2 4 4	Antenna — velocity sensor	232906	4.38	—
1 2 4 5	Waveguides		1.05	—
1 2 4 5 1	Waveguide assembly 1	232907	0.35	—
1 2 4 5 2	Waveguide assembly 2	232907	0.35	—
1 2 4 5 3	Waveguide assembly 3	232907	0.35	0
1 2 5	ONT power control system B	233400	8.80	4.50
1 2 6	T.V. camera No. 4	233102	7.20	—
1 2 7	Engineering signal process B	233350	6.15	3.5
1 2 8	Mechanical auxiliaries A	233312	2.27	1.22
1 2 9	Thermal control assembly		0.20	0.20
1 2 9 1	Heater control A	232110	0.10	0.10
1 2 9 2	Heater control B	232110	0.10	0.10
1 210	AMR—see code 5 3		0.00	0.00

^a As of 1-25-63.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 211	Insulation — see code 5 6		0.00	0.00
1 3	Electrical power		54.50	18.50
1 3 1	Solar panel	237700	8.50	8.50
1 3 2	Battery A	237900	46.00	10.00
1 4	Mechanisms		29.79	3.69
1 4 1	Pos — antenna + solar	236400	24.60	0.00
1 4 1 1	Arm, solar panel	237454-1	1.06	0
1 4 1 2	Arm, solar panel	237454-2	1.06	0
1 4 1 3	Mast, extension	237458	1.31	0
1 4 1 4	Support antenna, lower		0.45	0
1 4 1 5	Bracket, lower	260257	0.31	0
1 4 1 6	Support antenna, upper		3.02	0
1 4 1 7	Bracket, upper	237467	0.26	0
1 4 1 8	Housing E axis drive	237479	0.97	0
1 4 1 9	Flange mounting	237485	0.21	0
1 4 110	Tube, outer mast	237484	2.84	0
1 4 111	Bearing roll axis		0.35	0
1 4 112	Gear set + pin, etc.		2.90	0
1 4 113	Gas bottle	237527	0.63	0
1 4 114	Miscellaneous items bottle		0.43	0
1 4 115	Drive — solar axis	237187	1.76	0
1 4 116	Drive — elevation axis	237187-1	1.75	0
1 4 117	Drive — roll axis	237187-2	1.40	0
1 4 118	Drive — polar axis	236420	1.24	0
1 4 119	Solar axis fittings		0.28	0
1 4 120	Solar axis fittings		0.28	0
1 4 121	Pin puller + mounting S		0.88	0
1 4 122	Pin puller + mounting R		0.21	0
1 4 123	Pin puller + mounting E		0.20	0
1 4 124	Switch + lock + mounting		0.15	0
1 4 125	Pot + mounting		0.12	0
1 4 126	Bracket-connector	260059	0.03	0
1 4 127	Paint		0.50	0
1 4 2	Antenna mechanics omni A	236900	2.28	1.28
1 4 2 1	Tube-assembly		1.36	—

^aAs of 1-25-63.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 4 2 2	Fitting-clevis	237446	0.40	—
1 4 2 3	Support, clevis fitting	260074	0.34	—
1 4 2 4	Spring + miscellaneous		0.18	—
1 4 3	Antenna mechanics omni B	260000	1.26	0.76
1 4 3 1	Tube assembly		0.87	—
1 4 3 2	Pivot, spring + miscellaneous		0.39	—
1 4 4	Sep sensing + arm		1.65	1.65
1 4 4 1	No. 1	236190	0.55	0.55
1 4 4 2	No. 2	236190	0.55	0.55
1 4 4 3	No. 3	236190	0.55	0.55
1 5	Spacecraft vehicle		196.70	
1 5 1	Spacecraft basic structure		56.97	0
1 5 1 1	Spacecraft fittings		21.32	0
1 5 1 1 1	Fitting column base	230291	2.80	0
1 5 1 1 2	Fitting column base	230291	2.80	0
1 5 1 1 3	Fitting column base	230291	2.80	0
1 5 1 1 4	Fitting propellant tank support	230292-1	0.60	0
1 5 1 1 5	Fitting propellant tank support	230292-1	0.60	0
1 5 1 1 6	Fitting propellant tank support	230292-1	0.60	0
1 5 1 1 7	Fitting propellant tank support	230292-2	0.60	0
1 5 1 1 8	Fitting propellant tank support	230292-2	0.60	0
1 5 1 1 9	Fitting propellant tank support	230292-2	0.60	0
1 5 1 110	Fitting socket landing gear	230293	0.40	0
1 5 1 111	Fitting socket landing gear	230293	0.40	0
1 5 1 112	Fitting socket landing gear	230293	0.40	0
1 5 1 113	Fitting socket landing gear	230294	0.40	0
1 5 1 114	Fitting socket landing gear	230294	0.40	0
1 5 1 115	Fitting socket landing gear	230294	0.40	0
1 5 1 116	Fitting upper column	230295	1.19	0
1 5 1 117	Fitting upper column	230296	1.15	0
1 5 1 118	Fitting upper column	230297	1.18	0
1 5 1 119	Fitting lower center	261301	0.81	0
1 5 1 120	Fitting lower center	230298	0.78	0
1 5 1 121	Fitting lower center	230298	0.78	0
1 5 1 122	Fitting mast upper	230304	0.76	0

^aAs of 1-25-63.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 1 123	Fitting mast lower	230299	0.27	0
1 5 1 2	Spacecraft tubes		23.07	0
1 5 1 2 1	Tube main lower	230301-1	1.16	0
1 5 1 2 2	Tube main lower	230301-1	1.16	0
1 5 1 2 3	Tube main lower	230301-1	1.16	0
1 5 1 2 4	Tube main lower	230301-1	1.16	0
1 5 1 2 5	Tube main lower	230301-1	1.16	0
1 5 1 2 6	Tube main lower	230301-1	1.16	0
1 5 1 2 7	Tube main upper	230301-2	1.07	0
1 5 1 2 8	Tube main upper	230301-2	1.07	0
1 5 1 2 9	Tube main upper	230301-2	1.07	0
1 5 1 210	Tube column	230301-3	0.30	0
1 5 1 211	Tube column	230301-3	0.30	0
1 5 1 212	Tube column	230301-3	0.30	0
1 5 1 213	Tube base to landing gear	230301-4	0.21	0
1 5 1 214	Tube base to landing gear	230301-4	0.21	0
1 5 1 215	Tube base to landing gear	230301-4	0.21	0
1 5 1 216	Tube base to landing gear	230301-4	0.21	0
1 5 1 217	Tube base to landing gear	230301-4	0.21	0
1 5 1 218	Tube base to landing gear	230301-4	0.21	0
1 5 1 219	Tube column base to ML	230301-5	0.32	0
1 5 1 220	Tube column base to ML	230301-5	0.32	0
1 5 1 221	Tube column base to ML	230301-5	0.32	0
1 5 1 222	Tube column base to ML	230301-5	0.32	0
1 5 1 223	Tube column base to ML	230301-5	0.32	0
1 5 1 224	Tube column base to ML	230301-5	0.32	0
1 5 1 225	Tube cluster to ML	230301-6	0.60	0
1 5 1 226	Tube cluster to ML	230301-6	0.60	0
1 5 1 227	Tube cluster to ML	230301-6	0.60	0
1 5 1 228	Tube cluster to ML	230301-6	0.60	0
1 5 1 229	Tube cluster to ML	230301-6	0.60	0
1 5 1 230	Tube cluster to ML	230301-6	0.60	0
1 5 1 231	Tube up main to landing gear	230301-7	0.52	0
1 5 1 232	Tube up main to landing gear	230301-7	0.52	0
1 5 1 233	Tube up main to landing gear	230301-7	0.52	0

^aAs of 1-25-63.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 1 234	Tube up main to landing gear	230301-7	0.52	0
1 5 1 235	Tube up main to landing gear	230301-7	0.52	0
1 5 1 236	Tube up main to landing gear	230301-7	0.52	0
1 5 1 237	Tube mast tripod	230301-8	0.52	0
1 5 1 238	Tube mast tripod	230301-9	0.38	0
1 5 1 239	Tube mast tripod	230301-10	0.70	0
1 5 1 240	Tube mast base	230301-11	0.16	0
1 5 1 241	Tube mast base	230301-12	0.10	0
1 5 1 242	Tube mast base	230301-13	0.24	0
1 5 1 3	Pivot — landing gear		1.32	0
1 5 1 3 1	Pivot — landing gear	230224	0.44	0
1 5 1 3 2	Pivot — landing gear	230224	0.44	0
1 5 1 3 3	Pivot — landing gear	230224	0.44	0
1 5 1 4	Adapter — retro		2.40	0
1 5 1 4 1	Fitting retro adapter	230322	0.80	0
1 5 1 4 2	Fitting retro adapter	230322	0.80	0
1 5 1 4 3	Fitting retro adapter	230322	0.80	0
1 5 1 5	Bracing, including bolts	231362-C	5.26	0
1 5 1 6	Rivets, bolts, etc.	231362-D	3.60	0
1 5 2	Equipment attaching hardware		21.86	12.05
1 5 2 1	Flight sensor grip		1.18	0.60
1 5 2 1 1	Fitting lower	261404	0.10	—
1 5 2 1 2	Fitting lower	261405	0.12	—
1 5 2 1 3	Fitting lower	261406	0.10	—
1 5 2 1 4	Fitting main upper	261313	0.13	—
1 5 2 1 5	Fittings miscellaneous upper		0.23	—
1 5 2 1 6	Yoke upper brace	261779	0.05	—
1 5 2 1 7	Tubes		0.25	—
1 5 2 1 8	Bolts, rivets, etc.		0.17	—
1 5 2 1 9	Attach ground to support		0.03	—
1 5 2 2	Nitrogen tank	SP170231	1.54	0.50
1 5 2 2 1	Support left-hand	261346	0.20	—
1 5 2 2 2	Support right-hand	261347	0.13	—
1 5 2 2 3	Brace inboard	261348	0.04	—
1 5 2 2 4	Clevis	261354	0.02	—
1 5 2 2 5	Clevis	261355	0.03	—

^aAs of 1-25-63.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 2 2 6	Yoke	261356	0.04	—
1 5 2 2 7	Yoke	261357	0.04	—
1 5 2 2 8	Yoke	261358	0.03	—
1 5 2 2 9	Yoke	261359	0.05	—
1 5 2 210	Clevis	261379	0.09	—
1 5 2 211	Yoke	261179	0.02	—
1 5 2 212	Clevis	261387	0.03	—
1 5 2 213	Band assembly	230353	0.72	—
1 5 2 214	Bolts, rivets, etc.	230129	0.10	—
1 5 2 3	Att fig pneumatic lines		0.30	0.20
1 5 2 4	Brake roll jet leg 1		0.03	0.03
1 5 2 5	Brake pitch-yaw leg 2		0.05	0.03
1 5 2 6	Brake pitch-yaw leg 3		0.05	0.03
1 5 2 7	Radar alt marking		0.05	0.03
1 5 2 8	Signal data conver		0.35	0.35
1 5 2 9	Klystron power supply	230129-9A	1.26	0.63
1 5 2 9 1	Bracket	231149	0.62	—
1 5 2 9 2	Clevis (2)	231150	0.06	—
1 5 2 9 3	Yoke	231151	0.05	—
1 5 2 9 4	Yoke	261358	0.03	—
1 5 2 9 5	Clevis (2)	261387	0.06	—
1 5 2 9 6	Tube	261350-44	0.08	—
1 5 2 9 7	Tube	261350-47	0.04	—
1 5 2 9 8	Insulators, screws	230129	0.32	—
1 5 210	Altimeter sensor antenna		1.53	1.00
1 5 210 1	Two-tube support	230129	0.58	—
1 5 210 2	Three-tube support	230129	0.68	—
1 5 210 3	Brace	230129	0.27	—
1 5 211	Velocity sensor antenna		1.41	0.90
1 5 211 1	Two-tube support	230129	0.68	—
1 5 211 2	Three-tube support	230129	0.43	—
1 5 211 3	Brace	230108	0.30	—
1 5 212	Waveguide — doppler		0.25	0.25
1 5 212 1	Fixed supports	230129	0.09	0.09
1 5 212 2	Removable supports	230108-A	0.16	0.16
1 5 215	TV camera No. 4		1.00	0

^aAs of 1-25-63.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 216	Antenna + solar panel	230084	0.27	0
1 5 216 1	Screws solar panel	230107-4A	0.12	0
1 5 216 2	Screws planar array	230107-B	0.06	0
1 5 216 3	Screws mast — S/F	230084-A	0.09	0
1 5 217	Omni-antenna No. 2		0.79	0.79
1 5 217 1	Omni No. 2 lower		0.54	0.54
1 5 217 2	Omni No. 2 upper		0.10	0.10
1 5 217 3	Omni No. 1 pin puller		0.15	0.15
1 5 218	Omni antenna No. 1		0.43	0.43
1 5 218 1	Omni No. 1 lower		0.18	0.18
1 5 218 2	Omni No. 1 upper		0.10	0.10
1 5 218 3	Omni No. 1 pin puller		0.15	0.15
1 5 219	Separation sensor	230136-A	0.05	0.05
1 5 220	Release mechanism leg 1		0.17	0
1 5 220 1	Adapter — pin puller	230501	0.10	0
1 5 220 2	Bracket — pin puller	230188	0.02	0
1 5 220 3	Screws, nuts, etc.	230065-A	0.05	0
1 5 221	Release mechanism leg 2		0.17	0
1 5 221 1	Adapter — pin puller	230501	0.10	0
1 5 221 2	Bracket — pin puller	230188	0.02	0
1 5 221 3	Screws, nuts, etc.	230065-A	0.05	0
1 5 222	Release mechanism leg 3		0.17	0.17
1 5 222 1	Adapter — pin puller	230501	0.10	0
1 5 222 2	Bracket — pin puller	230188	0.02	0
1 5 222 3	Screws, nuts, etc.	230065-A	0.05	0
1 5 223	Auxiliary crush blocks		0.66	0
1 5 223 1	Fittings — 4 req No. 1	261688	0.20	0
1 5 223 2	Screws No. 1	230065-C	0.02	0
1 5 223 3	Fittings — 4 req No. 2	261688	0.20	0
1 5 223 4	Screws No. 2	230065-C	0.02	0
1 5 223 5	Fittings — 4 req No. 3	261688	0.20	0
1 5 223 6	Screws No. 3	230065-C	0.02	0
1 5 226	Compartment A		0.49	0
1 5 226 1	Lower support	231198	0.23	0
1 5 226 2	Lower support braces		0.15	0

^aAs of 1-25-63.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 226 3	Lower support attachment		0.06	0
1 5 226 4	Upper attachment		0.05	0
1 5 227	Compartment B		0.66	0
1 5 227 1	Main ctr lower		0.66	0
1 5 227 2	Brace ctr lower		0.09	0
1 5 227 3	Brace ctr lower		0.12	0
1 5 227 4	Upper yokes		0.10	0
1 5 227 5	Bolts, rivets		0.15	0
1 5 229	Fuel/oxidizer tanks		1.31	0.65
1 5 229 1	Brace inst leg 1	231068	0.28	—
1 5 229 2	Brace inst leg 2	231068	0.28	—
1 5 229 3	Brace inst leg 3	231068	0.28	—
1 5 229 4	Nuts lower attachment leg 1		0.03	—
1 5 229 5	Nuts lower attachment leg 2		0.03	—
1 5 229 6	Nuts lower attachment leg 3		0.03	—
1 5 229 7	Yoke outer leg 1	261179 (2)	0.04	0
1 5 229 8	Yoke outer leg 2	261179 (2)	0.04	0
1 5 229 9	Yoke outer leg 2	261179 (2)	0.04	0
1 5 22910	Yoke inner leg 1	261180 (2)	0.02	0
1 5 22911	Yoke inner leg 2	261180 (2)	0.02	0
1 5 22912	Yoke inner leg 3	261180 (2)	0.02	0
1 5 22913	Rivets		0.10	0
1 5 22914	Misc		0.10	0
1 5 235	Helium tank installation		1.96	0.71
1 5 236	Vernier engine No. 1		0.74	0.39
1 5 237	Vernier engine No. 2		0.73	0.38
1 5 238	Vernier engine No. 3		0.73	0.38
1 5 239	Eng meas sen No. 1		0.07	—
1 5 240	Eng meas sen No. 2		0.07	—
1 5 241	Eng meas sen No. 3		0.07	—
1 5 244	Vernier lines		1.97	1.97
1 5 245	Miscellaneous spacers		1.19	1.19
1 5 246	Radar marking antenna	261491	0.16	0.16
1 5 246 1	Support-connector	261491	0.09	0.09
1 5 246 2	Lanyard device	X230315	0.07	0.07

^aAs of 1-25-63.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 3	Paint-spaceframe		1.00	0.50
1 5 4	Landing gear inst.		39.09	0
1 5 4 1	Landing gear No. 1	261278	12.01	667
1 5 4 1 1	Locking strut	230254	1.15	—
1 5 4 1 2	A-frame assembly	230261	0.88	—
1 5 4 1 3	Shock absorber	230156	4.00	—
1 5 4 1 4	Leg assembly No. 1	230251	4.27	—
1 5 4 1 5	Landing gear No. 1 paint		0.20	—
1 5 4 1 6	Foot assembly	230266	0.94	—
1 5 4 1 7	Spring, A-frame left-hand	230264	0.15	—
1 5 4 1 8	Spring, A-frame right-hand	230286	0.15	—
1 5 4 1 9	Spring, foot left-hand	230265	0.02	—
1 5 4 1 10	Spring, foot right-hand	230476	0.02	—
1 5 4 1 11	Bolt, foot attachment	988033-390	0.11	—
1 5 4 1 12	Pin, locking strut	230225	0.01	—
1 5 4 1 13	Bolt, shock absorber	988033-314	0.03	—
1 5 4 1 14	Hardware		0.08	—
1 5 4 2	Landing gear No. 2	261279	12.01	6.67
1 5 4 2 1	Locking strut	230254	1.15	—
1 5 4 2 2	A-frame assembly	230261	0.88	—
1 5 4 2 3	Shock absorber	230156	4.00	—
1 5 4 2 4	Leg assembly No. 2	230252	4.27	—
1 5 4 2 5	Leg No. 2 paint		0.20	—
1 5 4 2 6	Foot assembly	230266	0.94	—
1 5 4 2 7	Spring, A-frame left-hand	230264	0.15	—
1 5 4 2 8	Spring, A-frame right-hand	230286	0.15	—
1 5 4 2 9	Spring, foot left-hand	230265	0.02	—
1 5 4 2 10	Spring, foot right-hand	230476	0.02	—
1 5 4 2 11	Bolt, foot attachment	988033-390	0.11	—
1 5 4 2 12	Pin, locking strut	230225	0.01	—
1 5 4 2 13	Bolt, shock absorber	988033-314	0.03	—
1 5 4 2 14	Hardware		0.08	—
1 5 4 3	Landing gear No. 3	261280	12.01	6.67
1 5 4 3 1	Locking strut	230254	1.15	—
1 5 4 3 2	A-frame assembly	230261	0.88	—

^aAs of 1-25-63.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 4 3 3	Shock absorber	230156	4.00	—
1 5 4 3 4	Leg assembly No. 3	230253	4.27	—
1 5 4 3 5	Landing gear No. 3 pint		0.20	—
1 5 4 3 6	Foot assembly	230266	0.94	—
1 5 4 3 7	Spring, A-frame left-hand	230264	0.15	—
1 5 4 3 8	Spring, A-frame right-hand	230286	0.15	—
1 5 4 3 9	Spring, foot left-hand	230265	0.02	—
1 5 4 3 10	Spring, foot right-hand	230476	0.02	—
1 5 4 3 11	Bolt, foot attachment	988033-390	0.11	—
1 5 4 3 12	Pin, locking strut	230225	0.01	—
1 5 4 3 13	Bolt, shock absorber	988033-314	0.03	—
1 5 4 3 14	Hardware		0.08	—
1 5 4 4	Pin pullers		0.57	—
1 5 4 4 1	Pin release mechanism No. 1	236390	0.19	—
1 5 4 4 2	Pin release mechanism No. 2	236390	0.19	—
1 5 4 4 3	Pin release mechanism No. 3	236390	0.19	—
1 5 4 5	Auxiliary crush blocks		2.49	—
1 5 4 5 1	Auxiliary crush shock 1	261281	0.13	—
1 5 4 5 1 1	Honeycomb block	261412	0.28	—
1 5 4 5 1 2	Adapter, honeycomb	230504	0.33	—
1 5 4 5 1 3	Cap, corrugated	230319	0.01	—
1 5 4 5 1 4	Insulator, shield	230505	0.19	—
1 5 4 5 1 5	Bond, crush shock		0.02	—
1 5 4 5 2	Auxiliary crush shock 2	261281	0.83	—
1 5 4 5 2 1	Honeycomb block	261412	0.28	—
1 5 4 5 2 2	Adapter, honeycomb	230504	0.33	—
1 5 4 5 2 3	Cap, corrugated	230319	0.01	—
1 5 4 5 2 4	Insulator, shield	230505	0.19	—
1 5 4 5 2 5	Bond, crush shock		0.02	—
1 5 4 5 3	Auxiliary crush shock 3	261281	0.83	—
1 5 4 5 3 1	Honeycomb block	261412	0.28	—
1 5 4 5 3 2	Adapter, honeycomb	230504	0.33	—
1 5 4 5 3 3	Cap, corrugated	230319	0.01	—
1 5 4 5 3 4	Insulator, shield	230505	0.19	—
1 5 4 5 3 5	Bond, crush shock		0.02	—

^aAs of 1-25-63.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 5 5	Compartment A		25.30	30.00
1 5 6	Compartment B		17.88	0
1 5 7	Wiring, basic bus		28.81	13.00
1 5 7 1	Wire — compartment A	231481	1.85	1.75
1 5 7 2	Wire — compartment B	261704	3.83	3.63
1 5 7 3	Wire — positioner	231479	2.67	0
1 5 7 4	Wire — retro motor	261575	0.30	0.30
1 5 7 5	Wire — thermal tunnel	261579	2.24	0
1 5 7 6	Wire — flight control	261590	5.07	2.37
1 5 7 7	Wire — doppler radar	261589	3.62	2.42
1 5 7 8	Wire — TV No. 4	261586	0.44	0
1 5 7 9	Wire — landing + explosive	261583	1.10	0
1 5 710	Wire — propulsion	261587	0.73	0.73
1 5 711	Wire — engineering measure	261591	1.49	0.79
1 5 712	Wire — planar antenna	261701	1.50	0.00
1 5 713	Wire—omni No. 1	261702	1.04	0.54
1 5 714	Wire—omni No. 2	261703	1.00	0.50
1 5 715	Tunnel, clmrs insul		1.93	0.30
1 5 8	Lines — attitude control	230125	0.84	0.44
1 5 8 1	Line — tank	231363	0.03	—
1 5 8 2	Line — leg 3	231364	0.04	—
1 5 8 3	Line — leg 2	231365	0.04	—
1 5 8 4	Line — leg 1	231366	0.05	—
1 5 8 5	Line — long sector 2	231367	0.07	—
1 5 8 6	Line — short sector 2	231368	0.05	—
1 5 8 7	Line — sector 1	231369	0.09	—
1 5 8 8	Line — flexible leg 1	261299	0.10	—
1 5 8 9	Line — flexible leg 2	261299	0.10	—
1 5 810	Line — flexible leg 3	261299	0.10	—
1 5 811	Cross	230125	0.03	—
1 5 812	Screws, clamps, etc.	230125	0.14	—
1 5 9	Release mechanism retro rocket		1.71	1.21
1 5 9 1	Release mechanism retro		0.57	0.41
1 5 9 2	Release mechanism retro		0.57	0.40
1 5 9 3	Release mechanism retro		0.57	0.40
1 510	Eng measure sensor		2.34	1.00

^aAs of 1-25-63.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 510 1	Accelerometer		0.30	—
1 510 2	Accelerometer amplifier		1.50	—
1 510 3	Sensors		0.54	—
1 512	Latch spacecraft — Centaur		0.90	0.90
1 512 1	Latch No. 1		0.30	0.30
1 512 2	Latch No. 2		0.30	0.30
1 512 3	Latch No. 3		0.30	0.30
1 6	Propulsion		78.69	—
1 6 1	Vernier propulsion system	238602	69.29	31.87
1 6 1 1	Helium valve assembly	238603	1.93	1.50
1 6 1 2	Helium tank — dry	238604	20.31	3.78
1 6 1 3	Fuel tank	238605	9.75	3.75
1 6 1 3 1	Fuel tank No. 1		3.25	1.25
1 6 1 3 2	Fuel tank No. 2		3.25	1.25
1 6 1 3 3	Fuel tank No. 3		3.25	1.25
1 6 1 4	Oxidizer tank	238606	9.72	3.72
1 6 1 4 1	Oxidizer tank No. 1		3.24	1.24
1 6 1 4 2	Oxidizer tank No. 2		3.24	1.24
1 6 1 4 3	Oxidizer tank No. 3		3.24	1.24
1 6 1 5	Thrust chamber assembly	238607	17.09	10.00
1 6 1 5 1	Thrust chamber No. 1		5.70	3.33
1 6 1 5 2	Thrust chamber No. 2		5.70	3.33
1 6 1 5 3	Thrust chamber No. 3		5.69	3.33
1 6 1 6	Thermal control — vernier system	238666	5.65	2.95
1 6 1 6 1	Helium tank	238653	0.22	0.22
1 6 1 6 2	Helium valve	238603	0.04	0.04
1 6 1 6 3	Helium lines	238602-10	0.08	0.08
1 6 1 6 4	Thrust chamber No. 1	238607	0.02	0.02
1 6 1 6 5	Thrust chamber No. 2	238607	0.02	0.02
1 6 1 6 6	Thrust chamber No. 3	238607	0.02	0.02
1 6 1 6 7	Propellant line — section 1	238668	0.25	0.25
1 6 1 6 8	Propellant line — section 2	238668	0.25	0.25
1 6 1 6 9	Propellant line — section 3	238668	0.25	0.25
1 6 1 610	Fuel tank No. 1		0.36	0.36
1 6 1 610 1	Standoff	238658	0.25	0.25

^aAs of 1-25-63.

JPL TECHNICAL MEMORANDUM NO. 33-150

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
1 6 1 610 2	Thermal coat	238605	0.11	0.11
1 6 1 611	Fuel tank No. 2		1.14	0.24
1 6 1 611 1	Standoff	238658	0.25	—
1 6 1 611 2	Insulation	238657	0.89	—
1 6 1 612	Fuel tank No. 3		0.36	—
1 6 1 612 1	Standoff	238658	0.25	—
1 6 1 612 2	Thermal coat	238605	0.11	—
1 6 1 613	Oxidizer tank No. 1		0.36	—
1 6 1 613 1	Standoff	238658	0.25	—
1 6 1 613 2	Thermal coat	238606	0.11	—
1 6 1 614	Oxidizer tank No. 2		1.14	0.24
1 6 1 614 1	Standoff	238658	0.25	—
1 6 1 614 2	Insulation	238657	0.89	—
1 6 1 615	Oxidizer tank No. 3		1.14	0.24
1 6 1 615 1	Standoff	238658	0.25	—
1 6 1 615 2	Insulation	238657	0.89	—
1 6 1 7	Lines + miscellaneous fittings	238602-11	4.84	3.34
1 6 1 7 1	Line + manifold		3.21	2.11
1 6 1 7 2	Transducer — He valve		0.30	0.30
1 6 1 7 3	Transducer — engine No. 3		0.60	0.40
1 6 1 7 4	Quick disconnects		0.73	0.53
1 6 2	Helium	231200-100	2.50	0.83
1 6 3	Propellant — unusable	231200-101	3.20	2.00
1 6 3 1	Unusable vernier fuel		0.43	—
1 6 3 2	Unusable vernier fuel		0.43	—
1 6 3 3	Unusable vernier fuel		0.43	—
1 6 3 4	Unusable vernier oxidizer		0.63	—
1 6 3 5	Unusable vernier oxidizer		0.64	—
1 6 3 6	Unusable vernier oxidizer		0.64	—
1 6 4	Main retro		3.70	3.70
1 6 4 1	Engine — see code 5 1		0.00	0
1 6 4 2	Insulation — see code 5 5		0.00	0
1 6 4 3	Safe — arm, main retro		3.70	3.70
2 0	Propellant — usable		150.69	61.1
2 1	Propellant — vernier	231200-101	150.69	—
2 1 1	Fuel — vernier		20.09	—

^aAs of 1-25-63.

Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
2 1 2	Fuel — vernier		20.09	—
2 1 3	Fuel — vernier		20.09	—
2 1 4	Oxidizer — vernier		30.14	—
2 1 5	Oxidizer — vernier		30.14	—
2 1 6	Oxidizer — vernier		30.14	—
2 2	Retro — see code 5 2		0	—
2 3	Ignition — see code 5 4		0	—
3 0	Scientific payload		130.40	35.0
3 1	TV cameras No. 2, 3		39.70	0
3 1 1	TV camera No. 2	233111	15.30	10.0
3 1 1 1	Camera		10.62	0
3 1 1 2	Filter		0.75	0
3 1 1 3	Mirror unit		3.93	0
3 1 2	TV camera No. 3	233112	15.30	0
3 1 2 1	Camera		10.62	0
3 1 2 2	Filter		0.75	0
3 1 2 3	Mirror unit		3.93	0
3 1 3	Instal hwd		4.30	0
3 1 3 1	Inst hwd No. 2		2.00	0
3 1 3 2	Inst hwd No. 3		2.30	0
3 1 4	Geo thermal/TV auxiliary A	232106	4.80	0
3 2	Surface sampler		10.00	10.0
3 2 1	Sampler-mech		8.00	0
3 2 2	Inst hwd		1.00	0
3 2 3	Auxiliaries — HAC A		1.00	0
3 3	Lunar soil measuring device		14.10	0
3 3 1	Instr + elect-JPL		9.00	0
3 3 2	Movable boom		3.00	0
3 3 3	Inst hwd		0.50	0
3 3 4	Auxiliaries—HAC B		1.60	0
3 4	Sample processor		16.20	0
3 4 1	Processor-mech		12.10	0
3 4 2	Inst hwd		0.90	0
3 4 3	Auxiliaries—HAC B		3.20	0
3 5	X-ray diffractomtr		16.30	0

^aAs of 1-25-63.

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Code	Item	Drawing No.	Surveyor ^a , lb	MSL, lb
3 5 1	HVPS — JPL	239240	8.00	0
3 5 2	Head — JPL	239214	7.00	0
3 5 3	Electronics — JPL B	239225	0.80	0
3 5 4	Auxiliaries — HAC B		0.50	0
3 5 5	Inst hwd — in 3.4		0	0
3 6	Alpha scattering device		7.10	0
3 6 1	Sensor — JPL	239304	1.00	0
3 6 2	Electronics — JPL B	239305	5.00	0
3 6 3	Auxiliaries — HAC B		1.10	0
3 6 4	Inst hwd — in 3.4		0	0
3 7	Micrometeorite, ejec det		13.00	0
3 7 1	Sensor — JPL	239309	8.00	0
3 7 2	Electronics — JPL B	239310	3.00	0
3 7 3	Auxiliaries — HAC B		1.50	0
3 7 4	Inst hwd		0.50	0
3 8	Engineering instruments		2.00	0
3 9	Wiring harness		12.00	0
	Batteries		—	15.0
^a As of 1-25-63.				